OLD CONCRETE BUILDING PATHOLOGY CASE STUDY

Lurdes Belgas[1]*, Jorge M. Mascarenhas[1], Fernando G. Branco[2]

1: CICC-Coimbra
Polytechnic Institute of Tomar
Campus da Quinta do Contador, 2300-454 Tomar, Portugal
e-mail: lbelgas@ipt.pt, jmascarenhas@ipt.pt, web: http://www.ipt.pt

2: INESC-Coimbra
University Lúrio
Campus da Unilúrio, Pemba, Moçambique
e-mail: fernando.branco@unilurio.ac.mz, web: http://www.unilurio.ac.mz/unilurio

Keywords: Rehabilitation, old buildings, reinforced concrete

Abstract

The use of reinforced concrete in construction is recent, starting by the end of the nineteenth century. Since the 30s of last century, the use of reinforced concrete in buildings and infrastructures became more popular and widespread.

In Portugal a lot of old buildings with reinforced concrete structure, built between the early 50s and late 70s of XX century, still exist.

These buildings, designed not according to 1983 regulation documents (Safety Regulations and Actions for Building and Bridges Structures) may have serious structural and foundation deficiencies, which may severely impair their ability to withstand intense earthquake.

Even in cases where the integrity of a structure of reinforced concrete is not jeopardized by poor performance, it is often necessary to adapt these older buildings to new uses or new performance requirements.

The present case study concerns an old reinforced concrete building, whose design dates from 1956. This is a building with an area of $(38 \times 10)\ m^2$, consisting of 7 floors, and containing a lower partially buried floor. At present the building is being subjected to an intervention for structural reinforcement and functional requalification to adapt to new use.

This article describes the main pathologies observed in the building before the intervention carried out and some of the rehabilitation works performed.

1. INTRODUCTION

In Portugal, there is still a considerable amount of old reinforced concrete buildings, built between the early 1950s and the late 1970s. These buildings were designed without seismic safety requirements, and they may present serious structural and foundation deficiencies, which can irreversibly condition their performance in the event of an earthquake. Frequently, throughout the times, these buildings were subjected to structural and functional refurbish which may further aggravate their behavior.

The older of these buildings were built using a reticulate structure consisting of reinforced concrete beams and columns. Usually, they were built with low strength concrete and external walls in ceramic bricks.

The structural systems presented a small degree of symmetry and regularity, with support solutions such as beam-beam and a very uneven distribution of columns. Sender beams and columns led to high deformability structures. The amount and detail of steel bars was not appropriate to provide the required ductility, as a consequence of the lack of specific regulations [1].

In 1961 a structural regulation (Regulation for Structural Loads in Buildings and Bridges (RSEP) was published. In 1967, the new Regulation of Reinforced Concrete Structures (REBA) was also published. Taking into account the evolution of seismic approach, reinforced concrete buildings built in the 1960s and 1970s are provided with reinforced stairwells and elevator towers. Concrete with better mechanical characteristics appeared, as an inevitable consequence of the increasing size of the buildings and larger spans.

The old reinforced concrete buildings show deficient structural performance as a result of poor project design, as well as resulting from interventions they may have suffered in their lifespan.

The present work describes a building which was built in the final years of 1950 decade, located in Lisbon. It is an imposing building, located in an important avenue, and is currently undergoing structural rehabilitation and functional restoration works. The scope of this paper is to identify and describe the major anomalies and remedial solutions adopted.

2. BUILDING CHARACTERIZATION

The building consists of a half basement floor, ground floor with an external access gallery, occupying six floors and a retreated upper floor. It was designed in 1956 by architect Carlos Pinheiro da Silva and contains a store on the ground floor and basement, and housing on the remaining floors (Figure 1). In December 1958, an application was made to change the use from residential to offices, and the new use was maintained until the present day.

The building has 330.74 m^2 deployment area, inserted in a 505.25 m^2 plot. It has a rectangular plan, a gable on the west side abuts another building and part of the south elevation abuts a lower building. The building contains some architectural aspects of interest, such as the walls, resulting in a composition of balconies and *brise soleil* on different planes, as well as the gallery in the ground floor. The most recent works of modern postwar architecture are known to influence the author of the design. However, interior design follows the traditional scheme of left / right fractions, in relation to a central corridor.

Figure 1. Building façade and a general view.

The basement use was divided in two separate areas: the restaurant and the shops. The elevators did not communicate with the basement. Between the ground floor and the basement, communication is made via stairs.

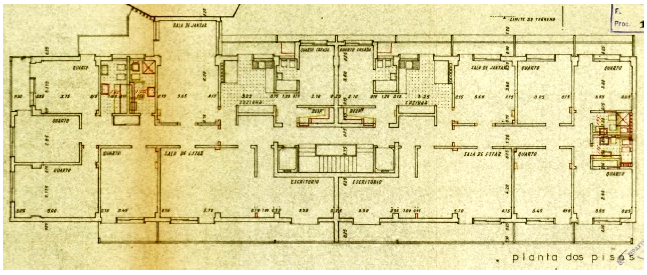


Figure 2. Floor design for floors 1 to 6 (copy of original design document)

The building consists of a portico structure containing concrete columns and beams of reinforced concrete. The foundations are straightforward, consisting only of isolated reinforced concrete sabots. During the preparation of the rehabilitation design project, surveys carried out showed no foundation beams, and the sabots were absent or of small size $(1{,}00\times1{,}00\times0{,}80)\ m^3$.

3. IDENTIFICATION OF MAIN CONSTRUCTIVE ANOMALIES

The building was built in the early days of concrete use in Portugal, thus presenting several anomalies due to limited technical knowledge and lack of specific regulations for this type of buildings.

Taking into account that this is an imposing and striking building of this era and that it is situated in a high seismic activity zone, its performance in the event of an earthquake is a major concern. In general it appears that the structural sections are insufficient and very slender. The steel bars in columns and beams are widely spaced, having been executed with thinly section smooth surface rods which minimizes steel-concrete adhesion conditions and the mechanical performance of concrete elements.

Structurally, the building was built with a gap between the level of floors and the supporting elements, that is, the slabs were not executed at the top level of the beams, but are supported on ceramic bricks placed on top of the beams. Therefore, no rigid connection exists between floor slabs and the respective beams.

The foundations are inadequate and practically non-existent, consisting of miniature isolate sabots (1,00×1,00×0,80) m^3 without locking beams.

The elements were manufactures using poor quality concrete consisting of large size aggregates and several rolled aggregates, which hinder the adhesion to the cement paste. A large number of voids is noticeable. A significant number of structural elements are sectioned by crossings of pipelines and cables.

4. MAIN INTERVENTIONS

The location of the building and its architectural quality justify a rehabilitation intervention and the change of its use. The building will revert to housing typology. However, the floor that originally had two fractions now will be divided in a larger number of fractions. Some of the old buildings in reinforced concrete have suffered interventions for structural reinforcement along the years. The main issues underlying the intervention relate to the mechanical characterization of existing materials, structural surveys and analysis of the strength and stability of structural elements against the planned adjustments and correct diagnosis of the anomalies found [2]. It is still frequent to exist large discrepancies between the design and in-situ execution as the work progresses.

After the diagnosis the most appropriate technical solution for rehabilitation is selected [3]. The suitability and durability estimated for the rehabilitated structure is crucial in the choice of the rehabilitation process. However, there are other variables that depend on the specific circumstances of each case.

Mechanical reinforcement of the foundations was carried out, with the implementation of a general mat foundation. Structural strengthening of the slabs, increasing the thickness from 10 to 18 cm and the timely reinforcement of beams and columns were also carried out. An important aspect was the modification of the structural system, with suppression or inclusion of new structural elements. For example, to include a new elevator in the building with the characteristics specified in the accessibility and mobility regulation (DL 163/2006 of August 8).

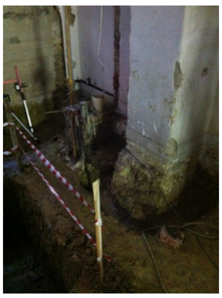
In the course of the rehabilitation project the real state of the building structure was not known. The designer had access to earlier intervention reports, which referred the enlargement of the basement columns, as well as changes in the 3rd and 4th floors where concrete beams were reinforced with steel beams and a partial demolition of some partition walls, and the addition of a recessed floor. These interventions could have had a positive action in strengthening the building structure, however it was realised that the enlargement of the basement columns was performed only with concrete, without the application of extra armor. At level 7, the extension of the structural elements was accomplished with small cross section columns to support beams that had a considerable size. This led to the postponement of the demolition of the masonry walls in this floor, because the roof was supported on the walls. Another aspect that weakened the strength of the pillars was the reduction in their section in the upper zone (zone connecting the slab) for placement of windows blinds (Fig. 3).

Figure 3. Example of concrete column in 7th floor, after removing the windows blinds.

At a later stage, a non-destructive and semi-destructive testing campaign was carried out in order to assess the characteristics and properties of materials used. In-situ tests were performed, including core drilling on the slabs and concrete beams and also the exterior walls. Geotechnical surveys were also carried out.

4.1. Foundations

During the excavation, a lack of foundation beams, which were represented in the existing structural design, was identified. One of the concrete columns was also missing. The foundations consisted mainly of insufficient and shallow dimension sabots. No foundation beams, no structural lock beams existed. Also, no elements to minimize the access of ground water to the basement were present. In an attempt to solve this problem, a concrete wall that connected the foundations of the main façade, which borders the public highway, was built. The solution adopted in this intervention was the implementation of a general mat foundation with two mesh armours, linked to micro-pegs performed at the base of the existing pillars. Micro pegs ensure a deeper foundation for the building and deeper mat foundation [4]. The loads transfer to the ground is also more uniformed.



a)

b)

Figure 4. a) No foundation column; b) Micro pegs and mat foundation armour.

Since the aim was to increase the cross-section of the columns, mat foundation rods were left that allowed the connection to the reinforcement of the subjacent columns. To ensure a good locking at the base of the pillars, mat foundation beams connecting the columns were incorporated. The connection of these beams to the column was ensured by fixing the rods with chemical anchors.

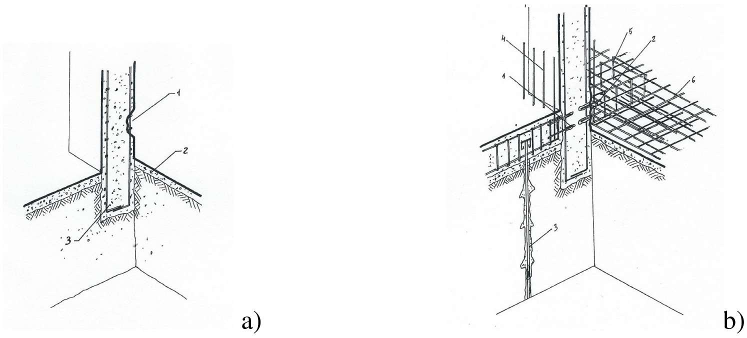


Figure 5. a) No foundation column; b) Connection of the beams to the column

Along with drilling holes for micro pegs, manual excavation of the drainage network pumping pit for sewage and storm water was carried out. The solution adopted allowed the initially planned piers to be dispensed, thus avoiding significant structural settlements.

Figure 6. Phases of the execution of the pumping pit

4.2. Columns

After removing the plaster and other coatings of the vertical structural elements, an exhaustive survey was carried out, to assess the location and size of the existing columns and beams. This action allowed the review of structures and architecture design, since the preliminary survey work carried out in the structure detected substantial differences from the original design. The columns, in addition to small cross-section, evidenced the existence of voids and reinforcing steel corrosion, with concrete detachment of the edges. The columns steel armour presented insufficient cross-section and smooth surface. The strengthening of the columns was carried out by concrete jacketing [5]. The columns were enveloped with a new armour and then a new layer of concrete was applied.. Special care was taken to scarify the original column surface to increase adhesion of the new concrete to the existing concrete, and also to let waiting steel rods for later connection to the new slabs, guaranteeing the continuity of the lining on the upper floors (see Fig.7).

4.3. Beams

The beams cross-section was also lower than expected, since they were lined with brick, and the straps were too much spaced and built with smooth surface small diameter rods (smooth reinforcement rods 6 mm in diameter and 15 cm apart straps). The beams were continually crossed by several infrastructures such as electrical wiring, networks of water, gas, etc.

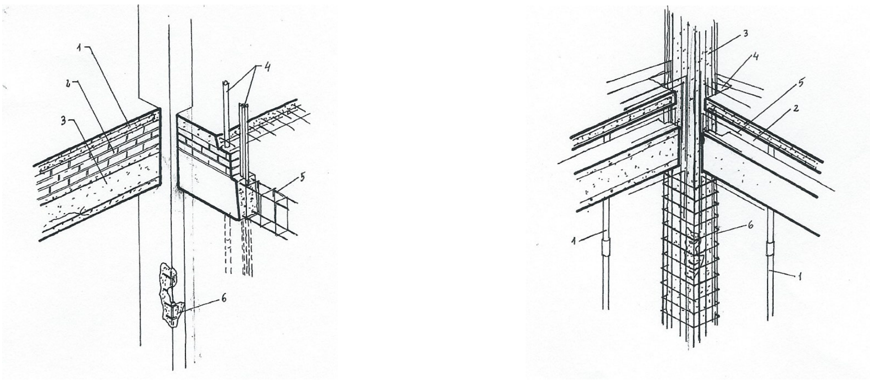


Figure 7. Anomalies in concrete columns and placement of reinforcement rods.

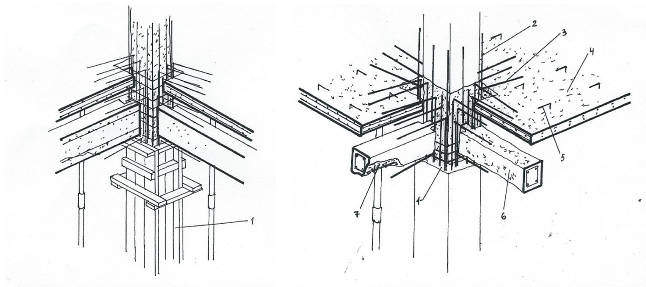
The beams were reinforced by a process identical to the pillars, i.e. placement of new reinforcement and filling with concrete. During this process, the slabs were properly anchored and the surface roughness of all the elements to be strengthened was guaranteed.

4.4. Slabs

In some slabs, besides the small thickness and armour deficit, there was the additional problem of not being connected to the beams, but supported on the beams through bricks.

However, the primitive slabs were kept for two major reasons: to keep intact the access ladder to the floor and to serve as a new slab formwork. The conservation of the original slabs also enabled keeping many of the interior walls.

a)



b)

Figure 8. a) Beam crossing; b) Column reinforcement continuity

Taking into account the existing constraints to make a new staircase in the building that complies with the regulations, it was decided to maintain the original set of stairs.

To ensure the monolithic connection between the slab and the beams, the support bricks were removed, and the beam height was increased to connect to the new slab. To improve the adhesion of the new slab to the former one connectors consisting of bent rods have been placed. In order to avoid infrastructure crossing of the beams, new openings were created in the slabs, properly positioned for passing *coretes.*


a)

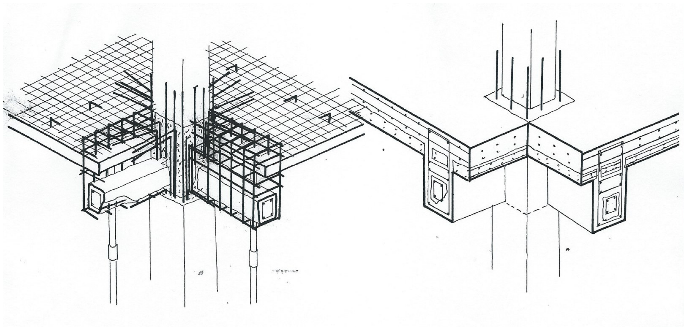

b)

Figure 9. a) Beams after caping removal; b) reinforcement armour and concrete casting

5. CONCLUSIONS

In Portugal, between the beginning of 1950 and the late 1970s, the building of reinforced concrete structures did not take into account the constructive provisions that allow mitigating the seismic action. Therefore existing buildings built in that period present huge structural and foundation shortcomings.

To perform the structural evaluation of an ancient building of reinforced concrete, it is important to survey the existing building, because the existing structural elements are often not built according to the original design, with regard to the location, geometry and detail, as well as the main mechanical properties of the building materials.

The present paper describes the rehabilitation and functional restoration of a building built in this period.

ACKNOWLEDGEMENTS

The authors wish to thank PLANIREST, Construções, Lda. for the opportunity of systematic monitoring of this work, and the additional information provided. Our thanks are particularly extended to Eng. Paulo Cordeiro and the project team.

REFERENCES

[1] S. Appleton (2008): Sismos e Edifícios, Amadora, Edições Orion, pp. 389-438.

[2] C. Vitor (2006): Inspecções e Ensaios na Reabilitação de Edifícios. IST press, Lisboa.

[3] NP EN 1504, (2006): Products and systems for the protection and repair of concrete structures. Definitions, requirements, quality control and evaluation of conformity, European Standard, CEN, Brussels. (Portuguese version)

[4] M. Jorge (2012): Sistemas de Construção – Reabilitação Urbana, Vol. XIII, Livros Horizonte, Lisboa.

[5] A. Gomes, Appleton, J., "Reforço de Estruturas de Betão Armado por Adição de Armaduras Exteriores". *Revista Portuguesa de Engenharia de Estruturas*, n.º 41, pp. 7-14, 1997.